NASA TM- 81923

NASA Technical Memorandum 81923

NASA-TM-81923 19810022582

PRELIMINARY RESULTS OF BUFFET TESTS IN A CRYOGENIC WIND TUNNEL

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JULY 1981

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SUMMARY

Buffet tests of two wings with different leading-edge sweep have shown that it is feasible to use the standard wing root bending moment technique in a cryogenic wind tunnel. The results for the 65° sweep delta wing indicate the importance of matching the reduced frequency parameter in model tests for planforms which are sensitive to reduced frequency parameter if quantitative buffet measurements are required. The unique ability of a pressurized cryogenic wind tunnel to separate the effects of Reynolds number and of aeroelastic distortion by variations in the tunnel stagnation temperature and pressure has been demonstrated.

INTRODUCTION

The study of techniques suitable for use in making buffet measurements in cryogenic wind tunnels is one of a number of studies in progress at the Langley Research Center in preparation for performing aerodynamic research in the National Transonic Facility (NTF) when it becomes operational (see ref. 1). Buffet can be defined as the structural response of an aircraft or test model to the aerodynamic excitation produced by separated flows. Since buffet is a separated flow phenomenon, it is, of course, dependent on Reynolds number. The NTF, with its capability to vary test Reynolds number over a very wide range, will present a unique opportunity for research in the area of buffet testing. The buffet tests described in this paper, which were carried out in the Langley 0.3 meter Transonic Cryogenic Tunnel (TCT), were based primarily on suggestions by Dennis G. Mabey of the British Royal Aircraft

Establishment at Bedford in a lecture (ref. 2) given at Langley. The primary objective of this study was to evaluate at cryogenic temperatures the use of an existing buffet testing technique, the measurement of the unsteady wing root bending moment. This evaluation would be done by obtaining comparable data at both ambient and cryogenic temperatures to validate the technique and the instrumentation. Secondary objectives were to utilize the unique capabilities of the cryogenic pressure tunnel to study the Reynolds number effect on buffet at constant dynamic pressure and to study the effect of model aeroelastic distortion on buffet at constant Reynolds number.

Two semispan buffet wing models similar to the ones suggested by Mabey in reference 2 were constructed and instrumented for these tests. One model is a slender, sharp leading edge delta wing with 65° leading edge sweep known to be relatively insensitive to Reynolds number. This configuration was chosen to provide a baseline model to demonstrate the test technique over the temperature range in a cryogenic wind tunnel. Mabey has previously reported on buffeting measurements on 65° sweep delta wings in reference 3. The other model is a zero sweep wing of aspect ratio 1.5 with an RAE (NPL) 9510 airfoil section which was expected to be very sensitive to differences in Reynolds number. The semispan wing models were cantilevered from a turntable located in the sidewall of the two-dimensional test section of the 0.3 m TCT. It is recognized there are wall interference effects because of the size of these three-dimensional models and the scheme of mounting the models; however, in comparing ambient and cryogenic results, wall effects should not be important.

Tests were made at subsonic Mach number over a range of stagnation pressures and at stagnation temperatures from 300 K to 100 K. The angle of

attack was varied from -4° to 32° for the delta wing model and from -2° to 18° for the NPL-9510 wing. Measurements were made of both the dynamic and the steady wing root bending moment. Some preliminary results from these tests are presented herein.

SYMBOLS

$\bar{c}$	mean geometric chord, meters
f	frequency, hertz
k	reduced frequency parameter, $\frac{\omega \bar{c}}{V}$, radians
$C_{B,D}$	dynamic wing root bending moment coefficient, $\frac{M_D}{qS\bar{c}}$
$C_{B,S}$	steady wing root bending moment coefficient, $\frac{M_S}{qS\bar{c}}$
K_T	root bending moment strain-gage sensitivity, newton-meter/ calibrate signal
M	free-stream Mach number
M_D	time averaged rms value of dynamic wing root bending moment, newton-meters
M_S	steady wing root bending moment, newton-meters
P_t	stagnation pressure, pascals
q	free-stream dynamic pressure, pascals
R	Reynolds number based on $\bar{c}$
S	reference area of semispan planform, meter^2
T_t	stagnation temperature, kelvin
V	free-stream velocity, meters/second
α	angle of attack, degrees

α_{ONSET}	angle of attack for buffet onset, degrees
ζ	total damping ratio, aerodynamic and structural, percent of critical damping
ρ	free-stream density, kilograms/meter^3
ω	angular frequency, $2\pi f$, radians/second

APPARATUS AND PROCEDURE

Wind Tunnel

The Langley 0.3 m Transonic Cryogenic Tunnel (TCT) is a single-return, fan-driven wind tunnel which utilizes nitrogen as the test gas. The two-dimensional test section presently installed in the tunnel circuit is 20.3 cm wide and 61.0 cm high. For this investigation the test section had a slotted floor, a slotted ceiling, and solid sidewalls. A motor-driven turntable which is 22.8 cm in diameter is centrally located in each sidewall for mounting two-dimensional airfoil models. The Mach number capability with the two-dimensional test section is from about 0.05 to 0.95. Stagnation pressure can be varied from about 122 kPa to about 608 kPa (1.2 atm to about 6.0 atm) and the stagnation temperature range is from about 77 K to 327 K. Additional information on the cryogenic tunnel concept and on the operating characteristics of the 0.3 m TCT are contained in references 1, 4 and 5.

Models

The two semispan buffet wing models were constructed from the same type of aluminium alloy, 7075-T6, as the turntable to which they were mounted.

This was done so as to minimize the effects of thermal expansion and contraction over the range of test temperatures in order to provide as rigid a model mounting as possible in order to keep the structural damping low. The mounting block at the root chord of each wing fit into a recessed cavity on the windward side of the turntable and was held in place by screws through the turntable with the threads in the mounting block. A square area about 1.9 cm on a side and 0.08 cm deep was machined into the upper and lower surfaces of the models near the root chord for placement of the root bending moment strain gage bridge. A strain gage bridge and two thermocouples were bonded with cement into the machined recesses. The remaining void was then filled to the original surface with the same cement which is rated for use over the temperature range of interest of 100 K to 300 K. No artificial transition was used to trip the boundary layer on either of the models for these tests. A sketch of the models is shown in figure 1 and a photograph of the two models is contained in figure 2. The model geometric characteristics are listed in table 1. A sketch of the test section of the 0.3 m TCT is shown in figure 3 and photographs of the models mounted in the 0.3 m TCT are in figures 4 and 5.

Instrumentation

The buffet data system used for these tests is a two-channel integrated unit designed by the personnel of the Instrument Research Division of the Langley Research Center. In the a.c. mode the system determines the average root-mean-square values of the unsteady voltage signal from the bending moment gage by integrating the time varying portion of the signal for a preselected time interval which may be varied from 1 to 99 seconds. For this test an

integration time of 20 seconds was used. The steady or d.c. voltages are automatically suppressed when the buffet system is operating in the a.c. mode. Variable gain settings are available in seven increments over a range from 200 to 20,000. Low-pass filters in the form of plug-in component boards are used to limit the frequency content above the range of interest. For this test the roll-off frequency was set at about 1000 hertz. The unsteady bending moment signal was recorded on a magnetic tape recorder for later off-line analysis. The buffet system also has a d.c. mode for wind-off calibration of the bending moment gage by application of known moments to the wing with weights. This d.c. mode was also utilized to measure the wind-on steady state root bending moments of the two wings.

Test Procedure

An electromagnetic shaker apparatus was used in an effort to determine the natural frequencies of the model wings, but the results obtained were inconsistent. The reason for this is believed to be related to the fact that the mass of the shaker head was large compared to the mass of the model wings. This can be a problem as mentioned in reference 6. Consistent results for the first natural frequency in bending were obtained by impulsively tapping on the wing and measuring the frequency of the output of the bending moment gages on an electronic frequency meter. For the delta wing the natural frequency at ambient temperatures is about 492 hertz while for the NPL-9510 wing the natural frequency at ambient temperatures is about 270 hertz.

Before the actual wind tunnel test, the models were loaded statically while in an environmental chamber in order to determine the effect of the large temperature range on the strain-gage sensitivity. The variation in

the sensitivity with temperature was found to be linear and to increase by 21 percent for the delta wing and 24 percent for the NPL-9510 wing over a range of temperature from 300 K to 110 K. This rather large change in sensitivity with temperature is the apparent result of the strain gages not being well matched to the aluminum alloy used for the models. A calibration of the sensitivity of the root bending moment gage with temperature for the delta wing model is shown in figure 6. The calibration curve for each of the two models as a function of temperature was used to correct the gage sensitivity in the data reduction.

After the wind tunnel had reached the required test conditions and the angle of attack had been set, the gain of the buffet system was adjusted to maximize the output of the unsteady wing root bending moment signal. This signal was monitored with an oscilloscope and a recording oscillograph for amplifier overload and for the allowable input range for the analog tape recorder. The unsteady bending moment signal was then integrated for the 20-second time interval chosen for this test and then recorded on the tunnel data system. Afterwards a 30-second segment of the unsteady signal was recorded on magnetic tape for later analysis. Then the steady root bending moment signal was measured and recorded on the tunnel data system. A separate desk top calculator was used to compute and plot the steady and the dynamic coefficients for on-line display.

RESULTS AND DISCUSSION

Delta Wing

The range of test conditions for the delta wing model is shown in figure 7 for a Mach number of 0.35 by the envelope of the Reynolds number

and the reduced frequency parameter combinations. The stagnation pressure and temperature are indicated along the boundaries of the envelope. The ability to provide this unique envelope with a single model is a result of the cryogenic tunnels ability to control velocity, and therefore to control reduced frequency, for a given Mach number by providing large changes in the speed of sound.

The results of the buffet tests for the delta wing model are presented in figures 8 through 12 with the steady and the dynamic wing root bending moment coefficients plotted as a function of the angle of attack. Figure 8 is a comparison of the results obtained at a Mach number of 0.35 at temperatures of 300 K and 110 K with the dynamic pressure held constant at 9.6 kPa. The steady bending moment data are seen to agree quite well. The dynamic bending moment data agree well up to the point of buffet offset where there is a marked change in slope at about 18° angle of attack with the curves diverging at the higher angles of attack, an effect which will be discussed later. The occurrence of buffet onset at 18° angle of attack correlates well with the results of Wentz and Kohlman in reference 7 for the angle of attack at which the breakdown of the leading edge vortex reaches the trailing edge of a 65° sweep delta wing. Figure 9 is a comparison of data at ambient and at cryogenic temperatures for $M = 0.35$ with the tunnel stagnation pressure adjusted so that the Reynolds number is constant. The results for the dynamic bending moment are similar to those in the preceding figure but the steady bending moments appear to show the effect of static model distortion under load as the steady bending moment coefficient is lower at the same angle of attack for the higher total pressure. Comparison of figure 8 with figure 9 confirms that there is negligible Reynolds number

effect for the 65° sweep delta wing model. Mabey has suggested in reference 8, based on the spectrum of pressure measurements on a different planform, that the large difference in the unsteady bending moment after buffet onset shown in both figures 8 and 9 is a result of the magnitude of the excitation spectrum increasing with the increase in reduced frequency parameter associated with the difference in ambient and cryogenic temperatures. As shown in figure 10, results were obtained at the same free-stream velocity, which gave almost the equivalent reduced frequency parameter, and the same dynamic pressure by adjusting the Mach number and the stagnation pressure. At these low Mach numbers any Mach number effect should be small. However, the effect of Mach number does appear in the steady bending moment as seen by the different slopes for the data at the Mach numbers of 0.21 and 0.35. Good agreement for the unsteady bending moment was obtained over the entire range of angle of attack using this procedure. This good agreement in the dynamic root bending moment is considered to be verification that the root bending moment strain-gage technique works satisfactorily at cryogenic temperatures. The variation in the reduced frequency parameter in figure 10 of 5.74 to 6.01 radians for the ambient and the cryogenic data respectively is a result of the frequency of the first natural bending mode increasing with a decrease in temperature because of an increase in modulus of elasticity of the aluminum alloy.

Figure 11 is a plot of the results with three different pressures at a Mach number of about 0.35 and a temperature of 300 K. The reduced frequency parameter is approximately constant. These data also show the effect of model distortion on both the steady and the dynamic bending moment as the high pressure causes a small decrease in the coefficients for both types of

bending moments. Figure 12 is a comparison of results at temperatures of 150 K and 110 K. Only a limited number of angle of attack points were taken in an effort to minimize test time by defining only the points around buffet onset. Good agreement was obtained for both the steady and the dynamic bending moments over the large range of Reynolds number.

NPL-9510 Wing

The steady and the dynamic wing root bending moment coefficients as a function of angle of attack for the NPL-9510 wing model are contained in figures 13 to 17. Figure 13 illustrates the large range of the buffet onset angle of attack from about 8° to 14° as a result of an increase in Reynolds number from 0.78×10^6 to 3.75×10^6 arising from a variation in the stagnation pressure from 122 kPa to 586 kPa. As previously mentioned, this wing was chosen with an airfoil section which should be sensitive to variations in Reynolds number. Figure 14 shows the results for a Mach number of 0.30 and a constant dynamic pressure of 34.7 kPa with stagnation temperatures of 300 K and 100 K with a resultant range of Reynolds number from 3.75×10^6 to 17.35×10^6. This figure shows the steady bending moment results to agree up to about 11° angle of attack and then diverge while the angle of attack for buffet onset decreases from about 14° to 11° in the dynamic bending moment results. Figure 15 also shows a comparison of four runs at a constant dynamic pressure of 28.9 kPa with a range of Reynolds number from 3.12×10^6 to 12.51×10^6. As can be seen in figure 16 with the Reynolds number held constant at 3.12×10^6, there is some difference in the level of the steady bending moment because of model aeroelastic distortion. In the dynamic bending moment there is no apparent change in buffet onset angle of attack

and the dynamic bending moment coefficients are insensitive to variations in the reduced frequency parameter. Adjusting the Mach number and the stagnation pressure in figure 17 to match the dynamic pressure and the free-stream velocity did not tend to collapse the dynamic bending moment curves for the NPL-9510 model as it did for the delta wing model. The buffet onset angle of attack differed by about 2°. This is thought to be a result of the Reynolds number sensitivity of this airfoil section.

The buffet onset angle of attack taken from figures 13 through 17 for the NPL-9510 wing model is summarized in figure 18 as a function of Reynolds number. With increasing values of Reynolds number the angle of attack for buffet onset is seen to rise from about 8° to a peak of about 14° and then to decrease to about 11°.

Damping Measurements

The structural damping of the model wings in still air at ambient temperature was measured from the trace of a recording oscillograph of the decay of the impulsive response. For the delta wing the damping was about 0.25 percent of critical and for the NPL-9510 wing the damping was about 0.67 percent of critical.

Values of the total damping ratio, aerodynamic plus structural, for some selected test conditions are listed in tables 2 and 3. These same damping ratio measurements are plotted in figures 19 and 20. The total damping ratio is seen to vary roughly as the product of the free-stream density and velocity. Measurements of the wind-on total damping ratio were made from a least squares fit of the decay of the envelopes of the auto-correlation functions. (See ref. 9.) The frequency of oscillation was

determined from the average time between peaks of the autocorrelation function. The analog signals recorded on magnetic tape were digitized at 3000 samples per second and about 5 seconds of data were processed by digital analysis techniques.

CONCLUDING REMARKS

Buffet tests of two wings with different leading-edge sweep have shown that it is feasible to use the standard wing root bending moment technique in a cryogenic wind tunnel. The results for the 65° sweep delta wing indicate the importance of matching the reduced frequency parameter in model tests for planforms which are sensitive to reduced frequency parameter if quantitative buffet measurements are required. The unique ability of a pressurized cryogenic wind tunnel to separate the effects of Reynolds number and of aeroelastic distortion by variations in the tunnel stagnation temperature and pressure has been demonstrated.

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8. Mabey, Dennis G.: Some Remarks on Buffeting. RAE Technical Memorandum Structures 980, February 1981.
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TABLE 1.- MODEL GEOMETRIC CHARACTERISTICS BASED ON SEMISPAN PLANFORMS

Delta Wing Model	
Leading edge sweep, deg	65
Trailing edge sweep, deg	0
Semispan, cm	9.48
Area, cm^2	96.26
Root chord, cm	20.32
Mean geometric chord, cm	13.55
Aspect ratio	0.93
Airfoil section	Flat plate with chamfered leading edge
RAE (NPL) 9510 Model	
Leading edge sweep, deg	0
Trailing edge sweep, deg	0
Semispan, cm	15.29
Area, cm^2	155.35
Root chord, cm	10.16
Mean geometric chord, cm	10.16
Aspect ratio	1.50
Airfoil section	RAE (NPL) 9510

TABLE 2.- VALUES OF THE TOTAL DAMPING RATIO FOR THE DELTA WING MODEL

M	P_t,kPa	T_t,K	ρ,kg/m^3	V,m/sec	$\frac{\rho V}{(\rho V)_{REF}}$	α,deg	f,Hz	ζ,%
0.35	122	300	1.33	120	0.60	0	495	1.51
↓	↓	↓	↓	↓	↓	10	↓	0.74
↓	↓	↓	↓	↓	↓	20	496	0.79
↓	↓	↓	↓	↓	↓	30	494	1.12
0.35	488	300	5.34	120	2.42	0	493	2.18
↓	↓	↓	↓	↓	↓	10	495	2.50
↓	↓	↓	↓	↓	↓	20	492	2.49
↓	↓	↓	↓	↓	↓	26	490	2.24
↓	↓	↓	↓	↓	↓	30	486	2.32
0.35	122	110	3.62	73	1.00	0	515	0.84
↓	↓	↓	↓	↓	↓	10	↓	1.42
↓	↓	↓	↓	↓	↓	20	↓	2.07
↓	↓	↓	↓	↓	↓	26	516	1.75
↓	↓	↓	↓	↓	↓	30	510	2.17
0.21	320	300	3.63	73	1.00	0	490	1.10
↓	↓	↓	↓	↓	↓	8	489	1.31
↓	↓	↓	↓	↓	↓	20	488	1.11
↓	↓	↓	↓	↓	↓	26	486	1.39
↓	↓	↓	↓	↓	↓	30	487	1.47

NOTE: $(\rho V)_{REF}$ is reference condition at $M = 0.35$, $P_t = 122$ kPa, and $T_t = 110$ K.

TABLE 3.- VALUES OF THE TOTAL DAMPING RATIO FOR THE NPL-9510 WING MODEL

M	P_t,kPa	T_t,K	ρ,kg/m^3	V,m/sec	$\frac{\rho V}{(\rho V)_{REF}}$	α,deg	f,Hz	ζ,%
0.30	488	300	5.42	103	2.45	0	272	1.80
↓	↓	↓	↓	↓	↓	10	268	1.43
↓	↓	↓	↓	↓	↓	15	269	1.40
↓	↓	↓	↓	↓	↓	18	268	1.47
0.30	122	110	3.68	62	1.00	0	288	1.24
↓	↓	↓	↓	↓	↓	10	286	--
↓	↓	↓	↓	↓	↓	15	282	0.95
↓	↓	↓	↓	↓	↓	18	283	0.83

NOTE: $(\rho V)_{REF}$ is reference condition at M = 0.30, P_t = 122 kPa, and T_t = 110 K.

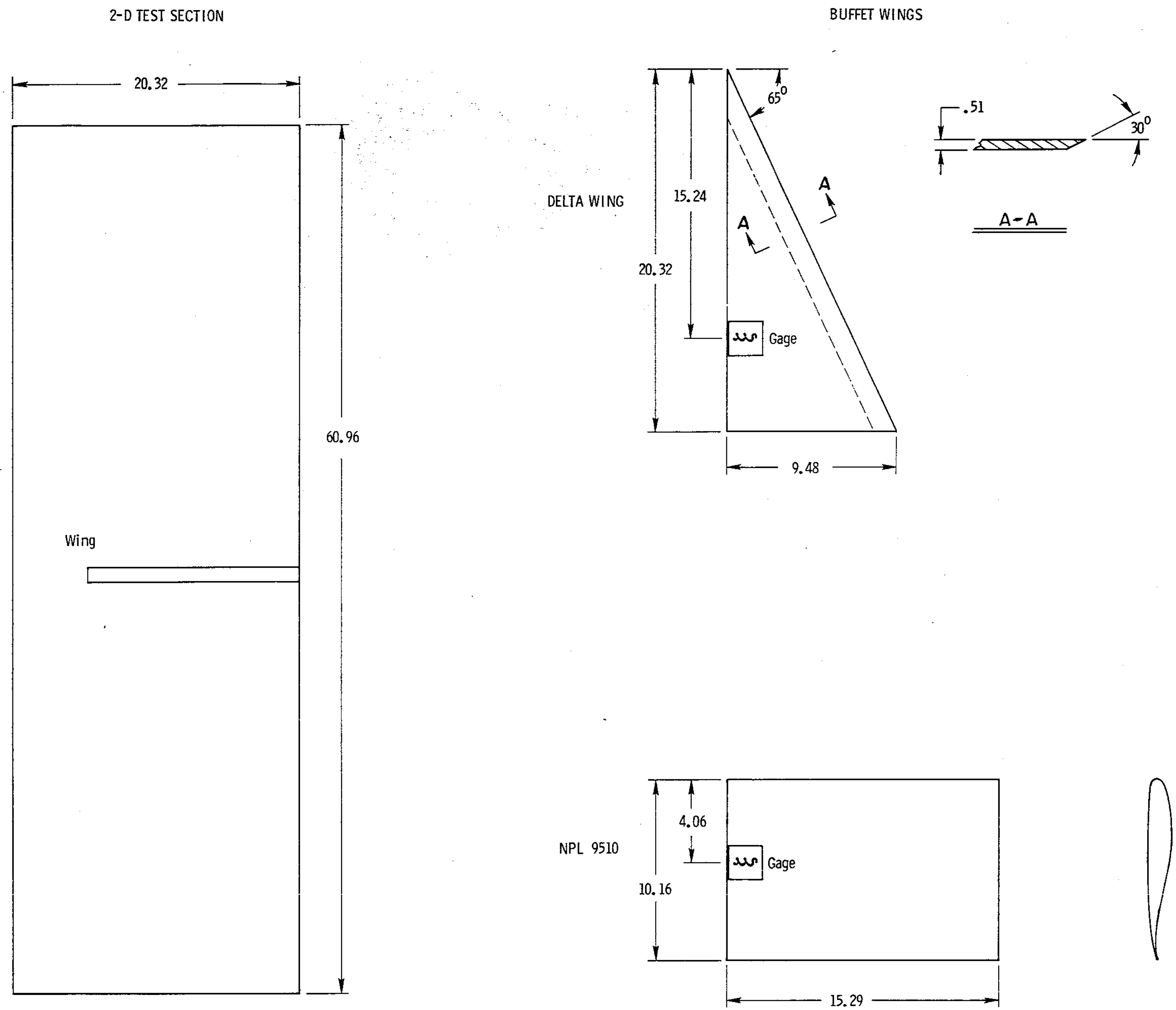


Figure 1.- Sketch of end view of test section of 0.3m Transonic Cryogenic Tunnel and the buffet models.

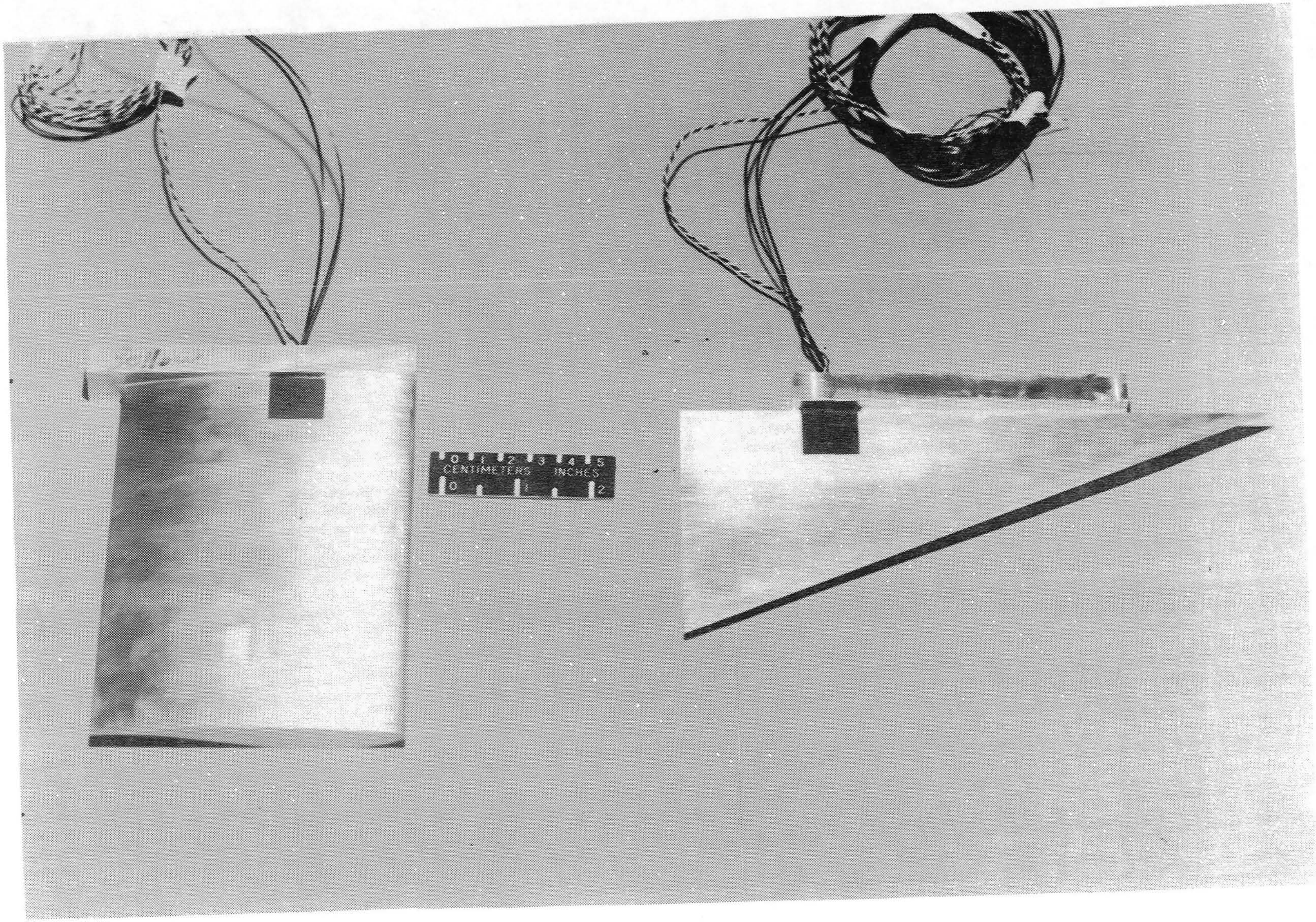


Figure 2.- Photograph of semi-span buffet wing models.

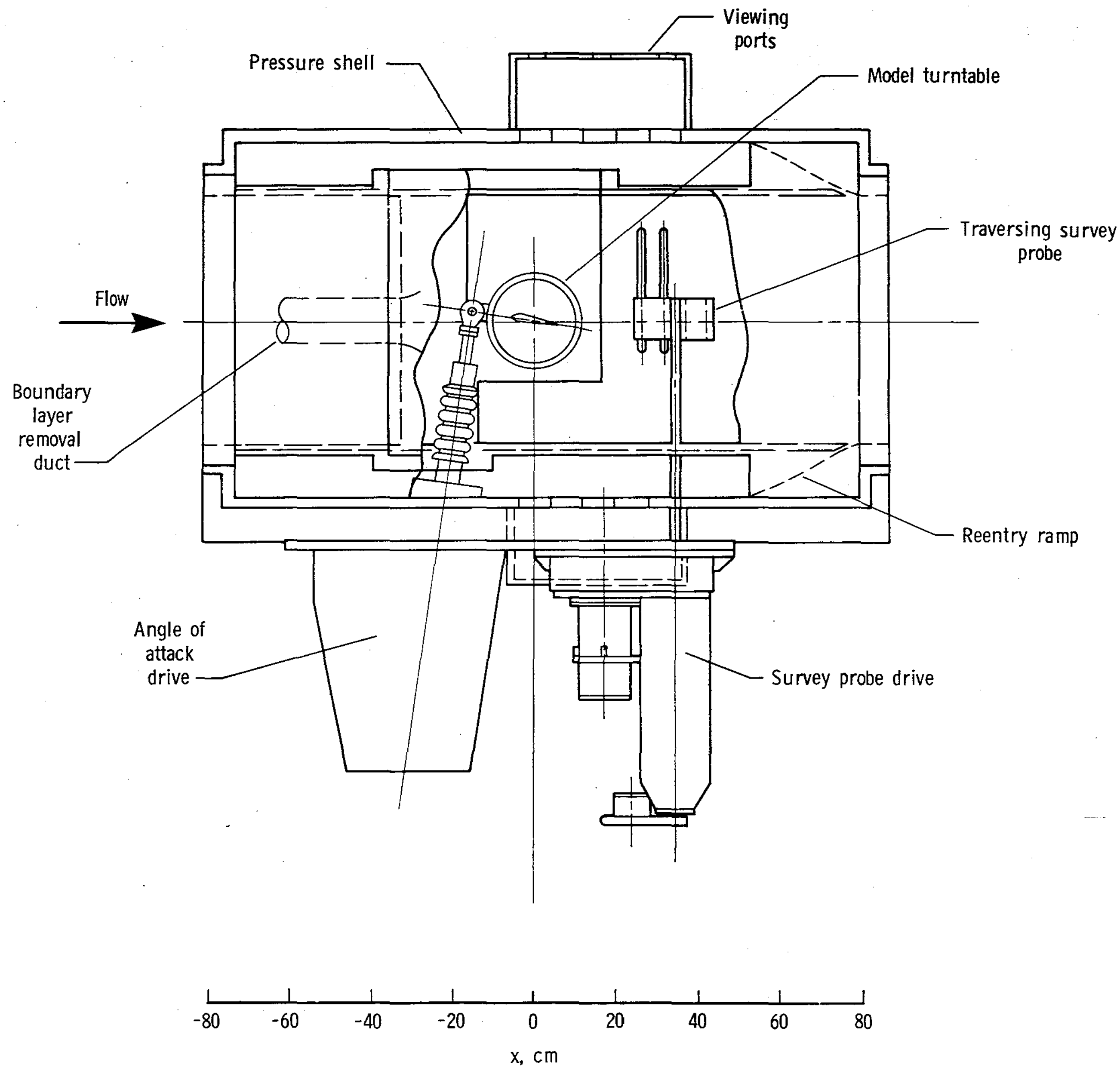


Figure 3.- Sketch of side view of two-dimensional test section of the 0.3m Transonic Cryogenic Tunnel.

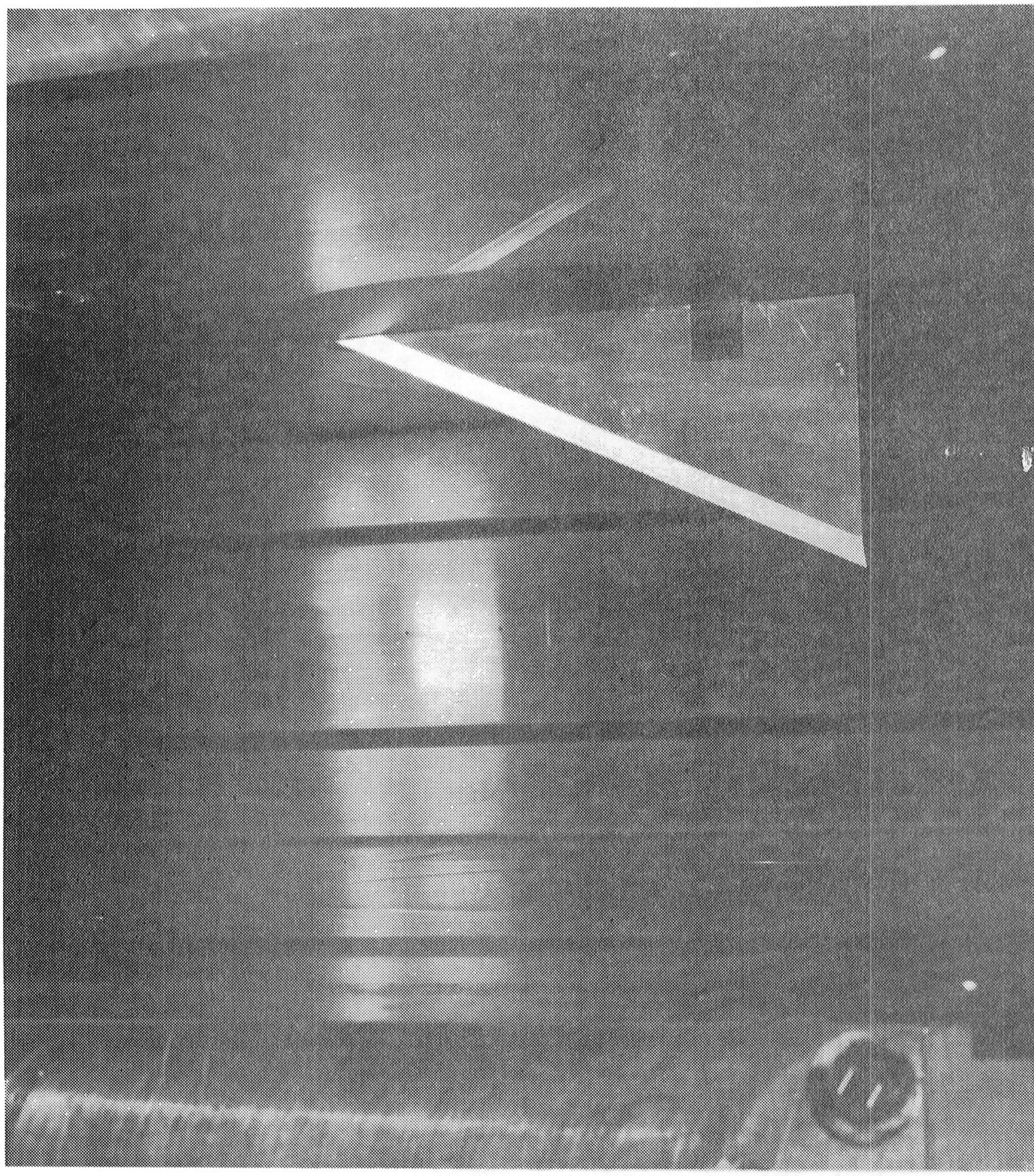


Figure 4.- Delta wing buffet model mounted in 0.3m Transonic Cryogenic Tunnel with the slotted floor in the background.

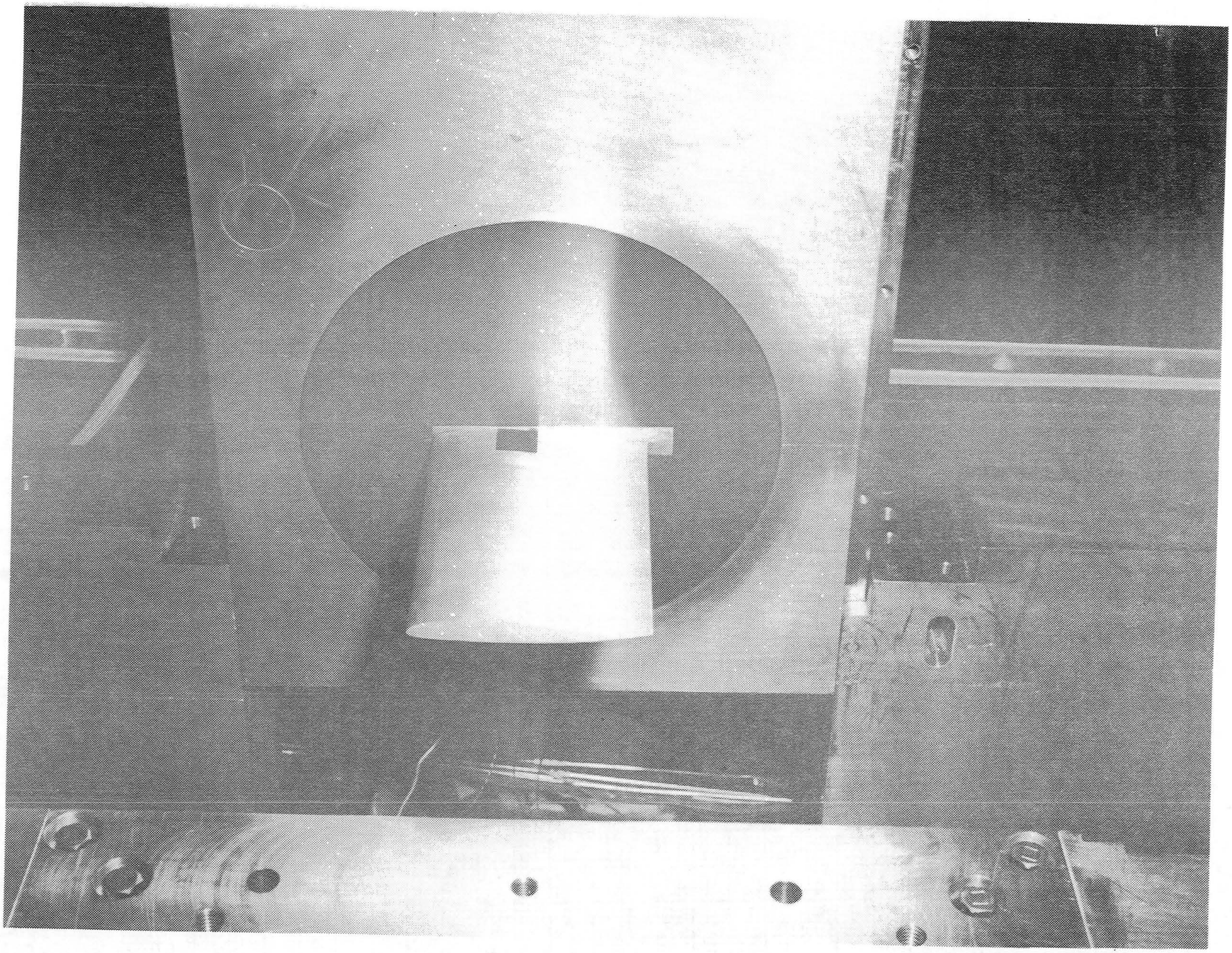


Figure 5.- RAE (NPL) 9510 wing buffet model mounted on turntable with sidewall insert raised in 0.3m Transonic Cryogenic Tunnel.

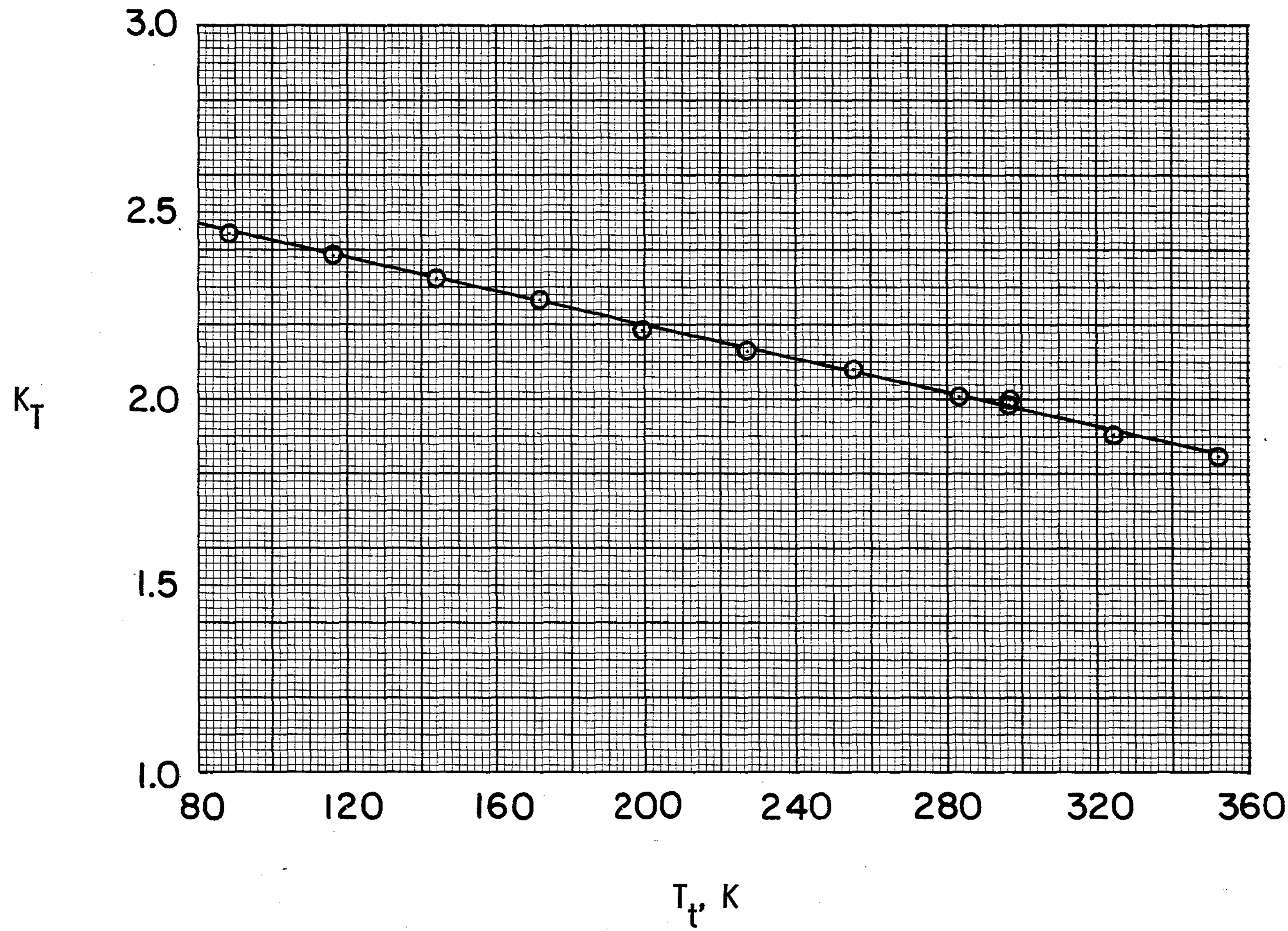


Figure 6.- Effect of temperature on root bending moment strain gage sensitivity for the delta wing model.

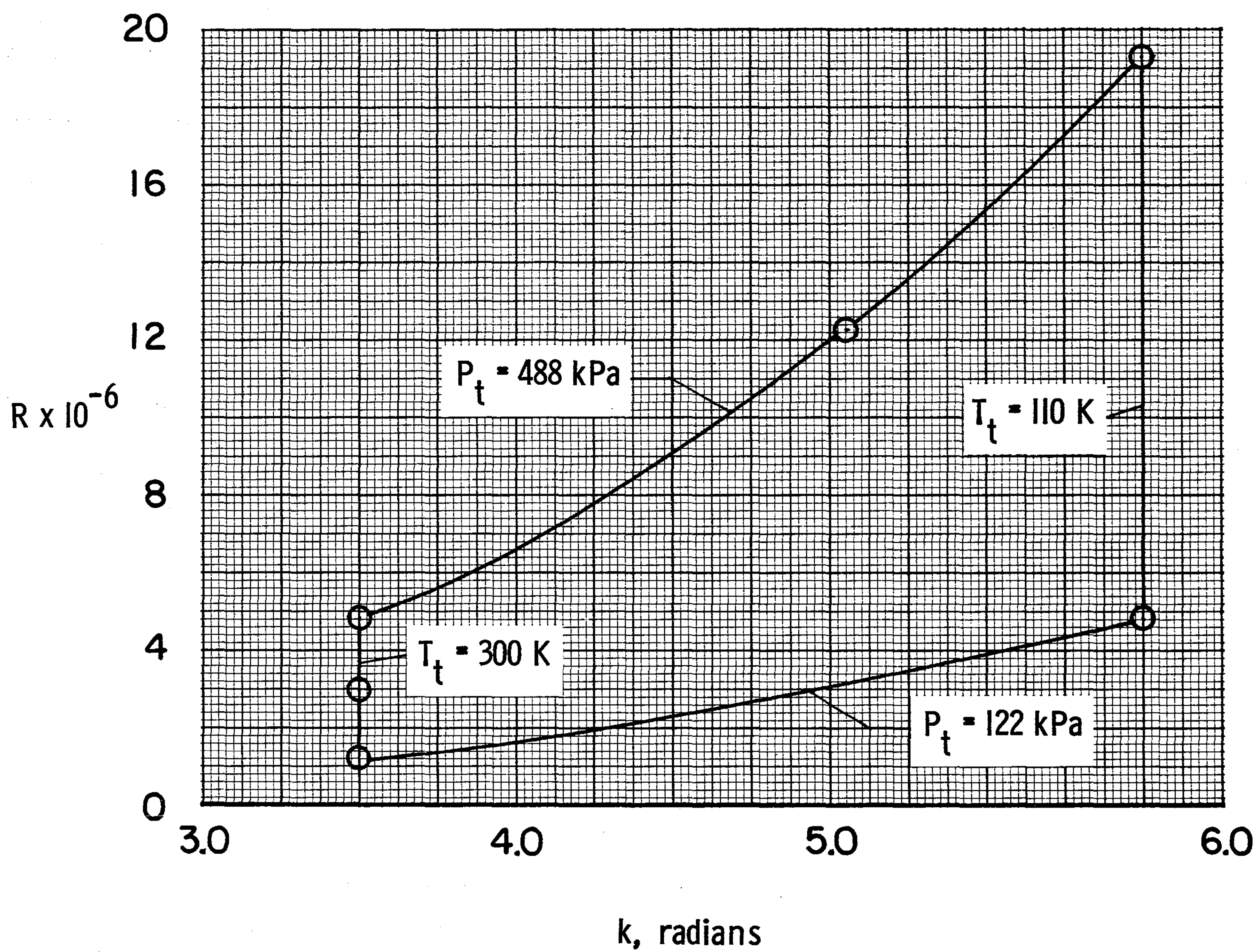


Figure 7.- Buffet test envelope for delta wing model in 0.3m Transonic Cryogenic Tunnel. M = 0.35

	M	P_t, kPa	T_t, K	$R \times 10^{-6}$	q, kPa	V, m/sec	k, rad
○	0.35	122	300	1.19	9.6	120	3.49
□	0.35	122	110	4.80	9.6	73	6.01

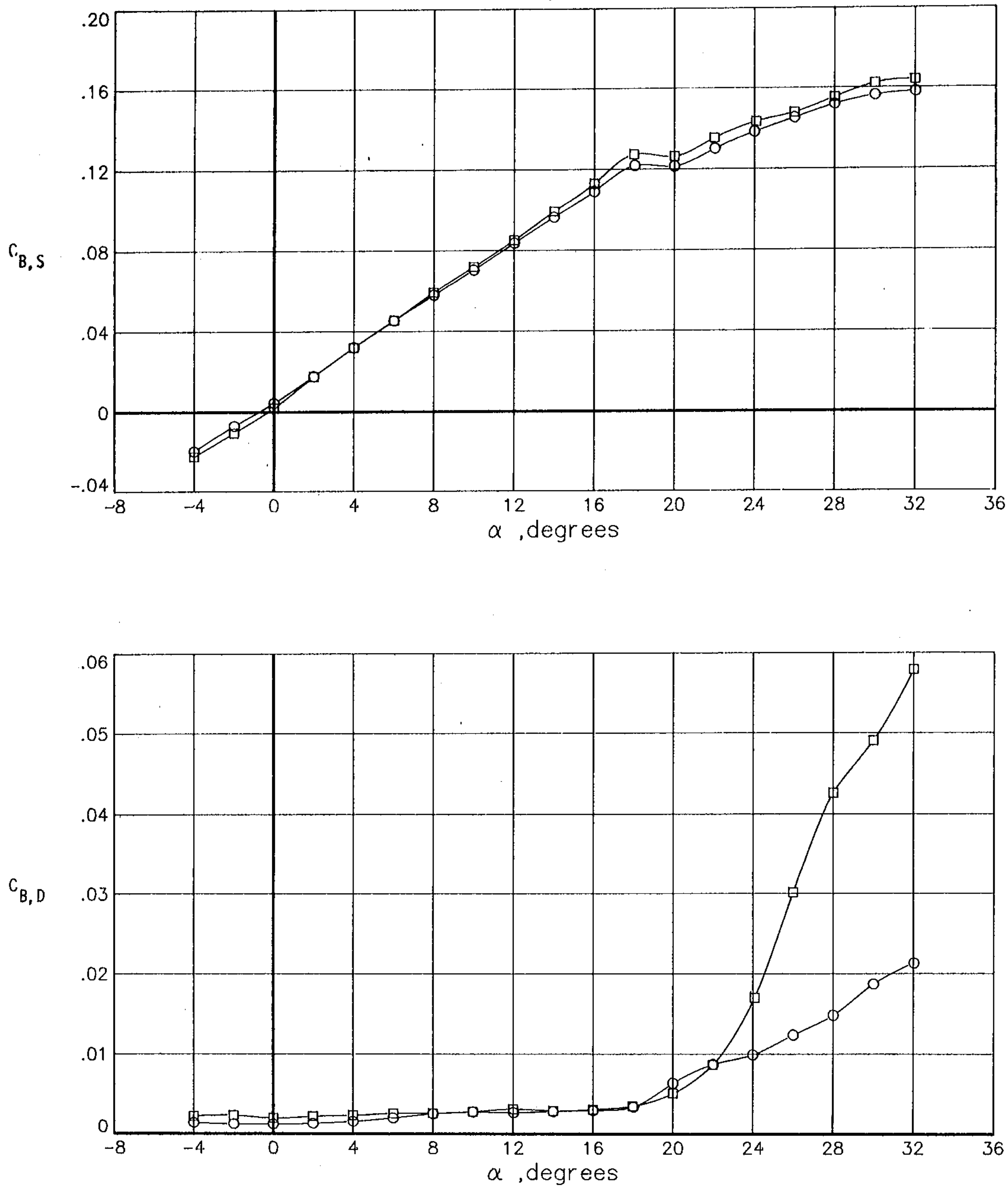


Figure 8.- Variation of steady and dynamic wing root bending moment coefficient with angle of attack for the delta wing model. $M = 0.35$, $P_t = 122$ kPa.

	M	P_t, kPa	T_t, K	R x 10^{-6}	q, kPa	V, m/sec	k, rad
○	0.35	488	300	4.80	38.5	120	3.49
□	0.35	122	110	4.80	9.6	73	6.01

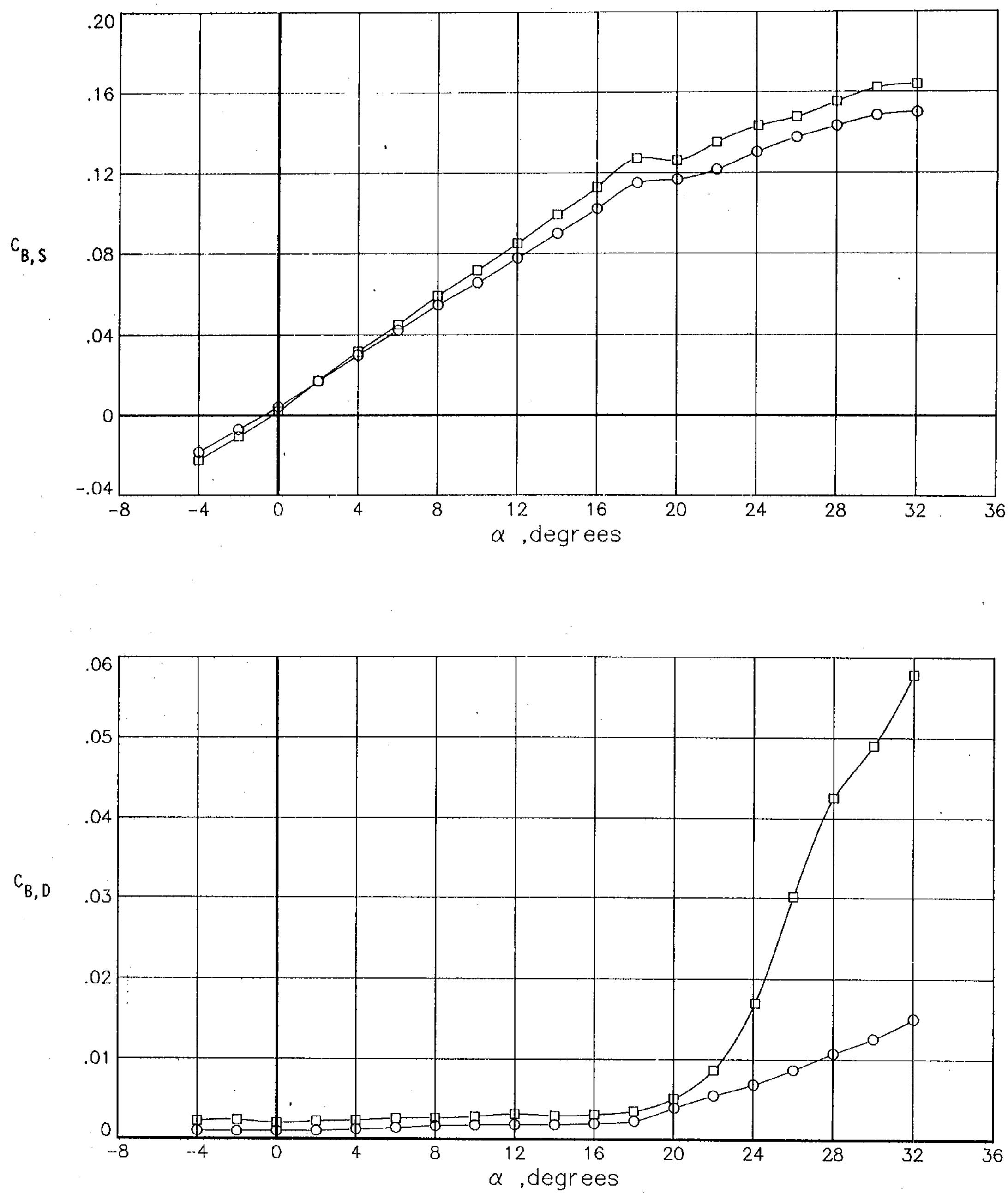


Figure 9.- Variation of steady and dynamic wing root bending moment coefficient with angle of attack for the delta wing model. M = 0.35, R = 4.80 x 10^6.

	M	P_t, kPa	T_t, K	R x 10^{-6}	q, kPa	V, m/sec	k, rad
○	0.21	320	300	1.95	9.6	73	5.71
□	0.35	122	110	4.80	9.6	73	6.01

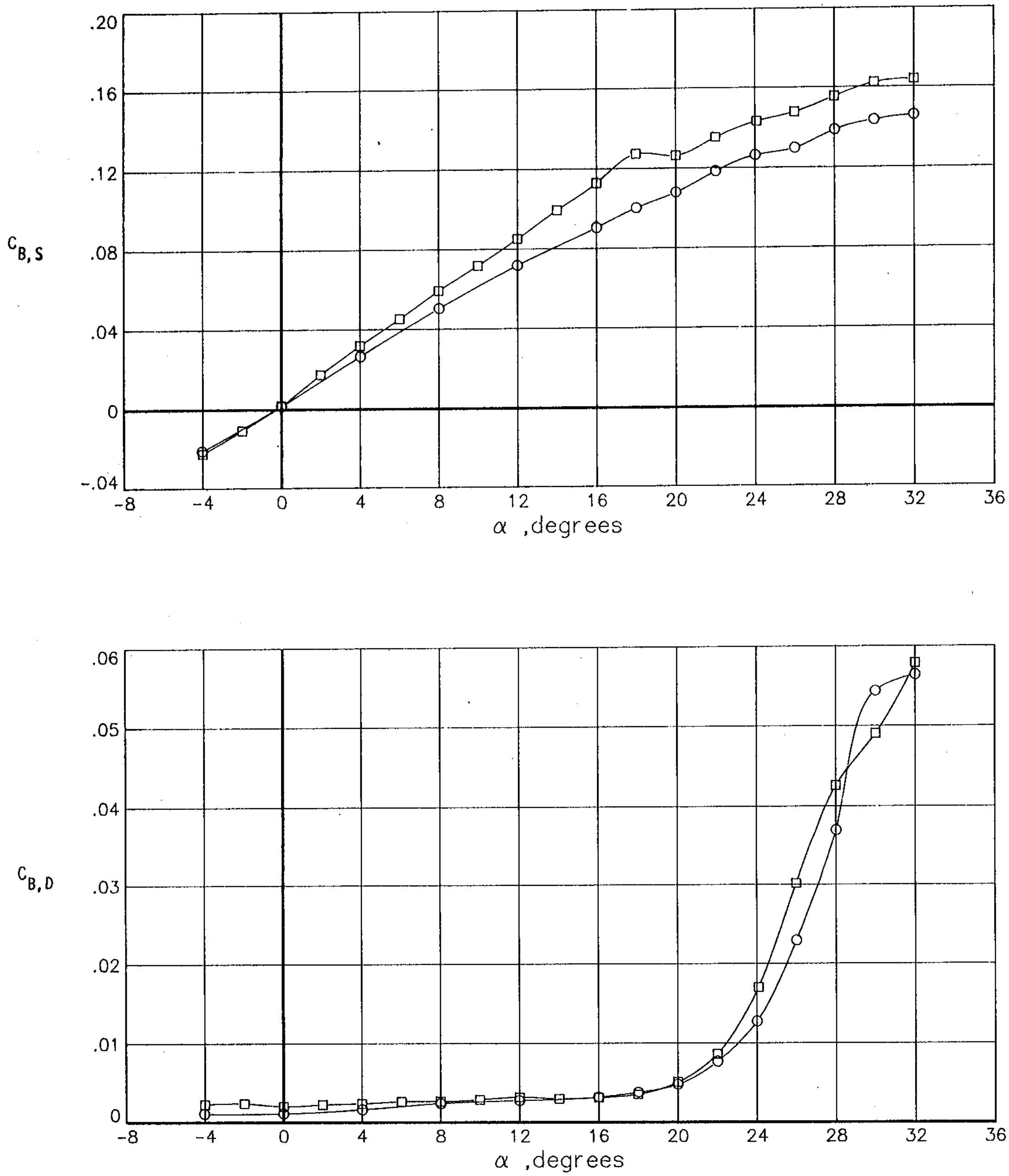


Figure 10.- Variation of steady and dynamic wing root bending moment coefficient with angle of attack for the delta wing model. V = 73 m/sec, q = 9.6 kPa.

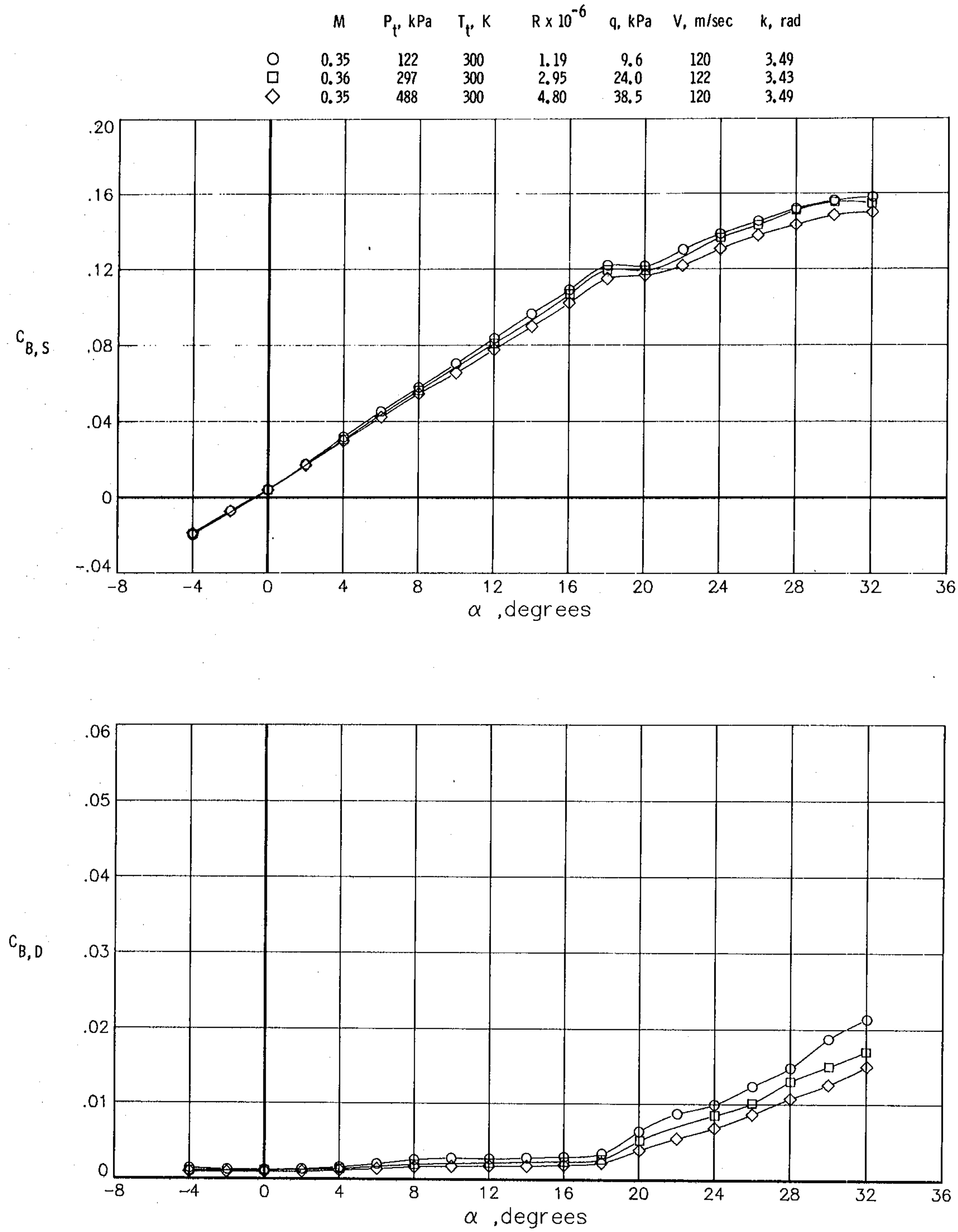


Figure 11.- Variation of steady and dynamic wing root bending moment coefficient with angle of attack for the delta wing model. $M \cong 0.35$, $T_t = 300$ K.

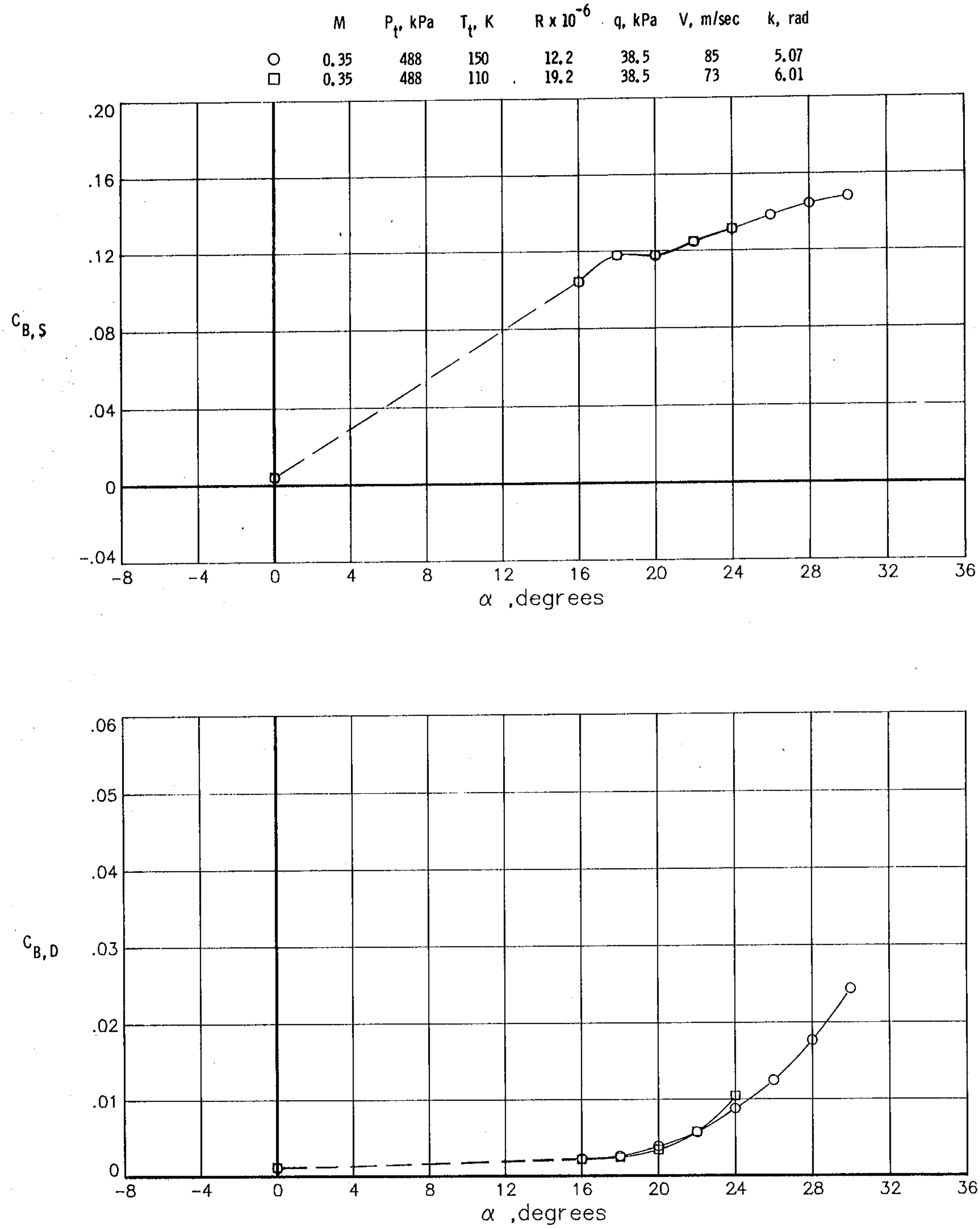


Figure 12.- Variation of steady and dynamic wing root bending moment coefficient with angle of attack for the delta wing model. $M = 0.35$, $P_t = 488$ kPa.

	M	P_t, kPa	T_t, K	R x 10^{-6}	q, kPa	V, m/sec	k, rad
○	0.30	122	300	0.78	7.2	103	1.67
□	0.30	243	300	1.55	14.4	103	1.67
◇	0.30	488	300	3.12	28.9	103	1.67
△	0.30	586	300	3.75	34.7	103	1.67

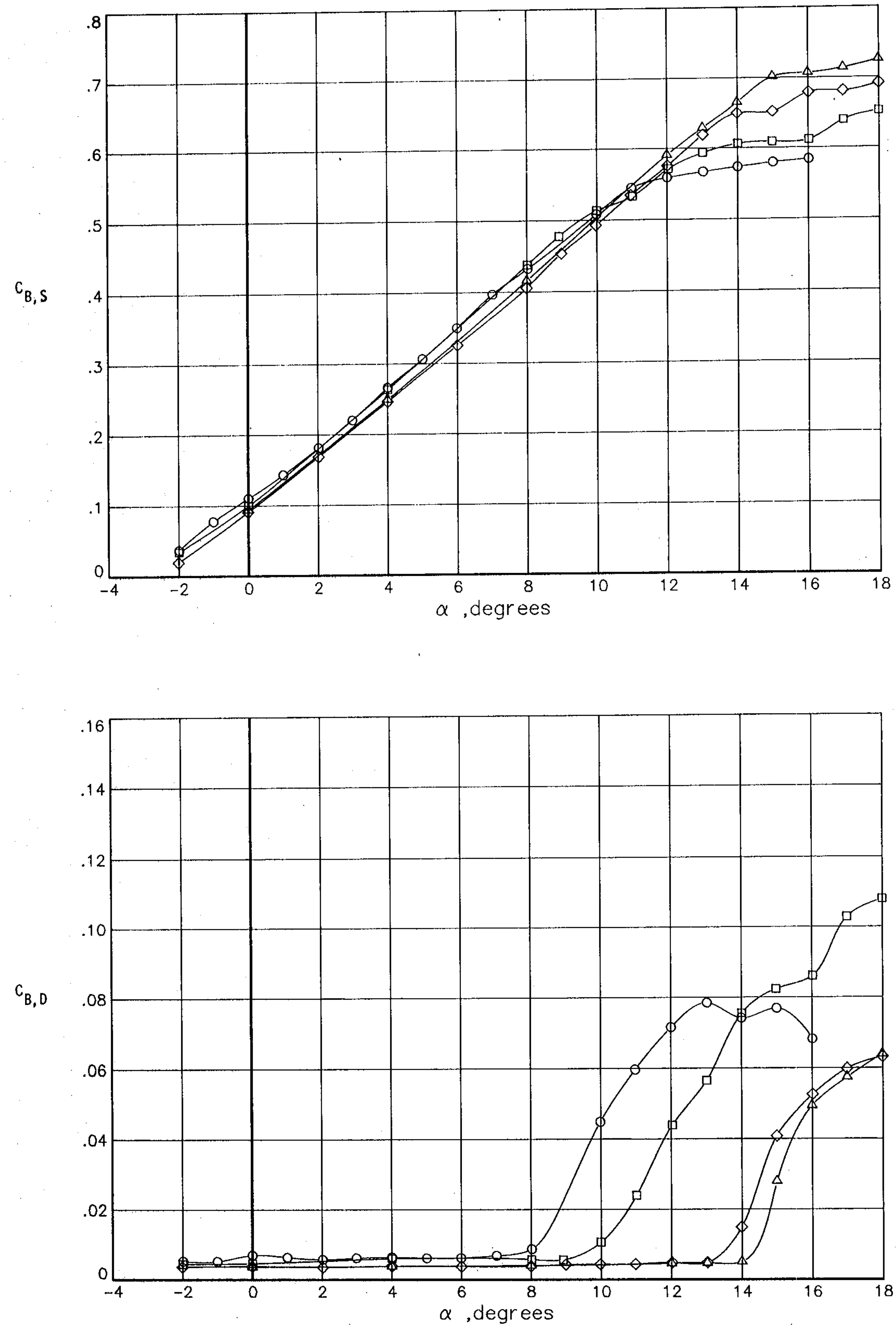


Figure 13.- Variation of steady and dynamic wing root bending moment coefficient with angle of attack for the NPL-9510 wing model. M = 0.30, T_t = 300 K.

	M	P_t, kPa	T_t, K	R x 10^{-6}	q, kPa	V, m/sec	k, rad
○	0.30	586	300	3.75	34.7	103	1.67
□	0.30	586	100	17.35	34.7	60	3.03

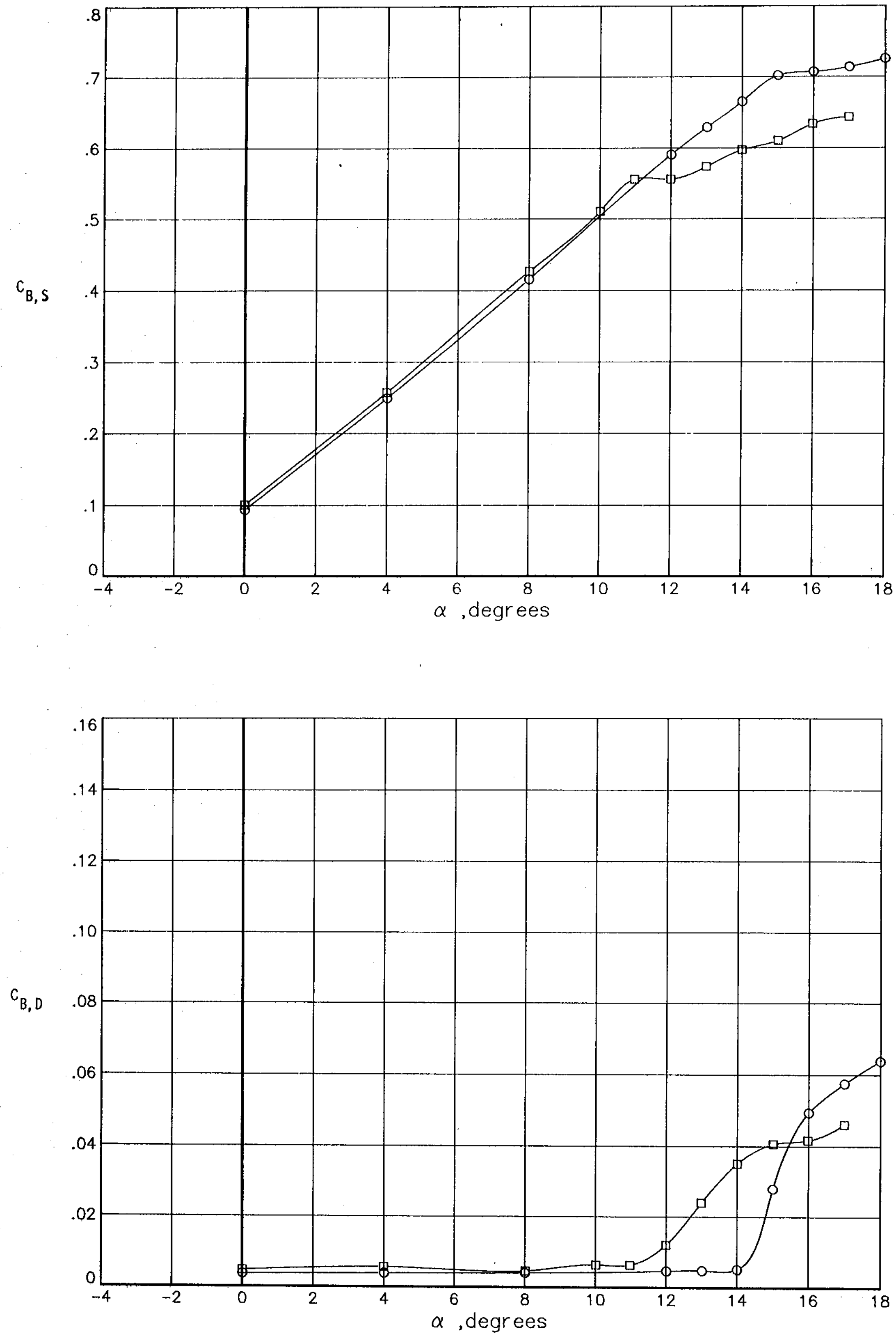


Figure 14.- Variation of steady and dynamic wing root bending moment coefficient with angle of attack for the NPL-9510 wing model. M = 0.30, P_t = 586 kPa.

	M	P_t, kPa	T_t, K	$R \times 10^{-6}$	q, kPa	V, m/sec	k, rad
○	0.30	488	300	3.12	28.9	103	1.67
□	0.30	488	150	7.93	28.9	73	2.46
◇	0.30	488	125	10.34	28.9	67	2.70
△	0.30	488	110	12.51	28.9	63	2.89

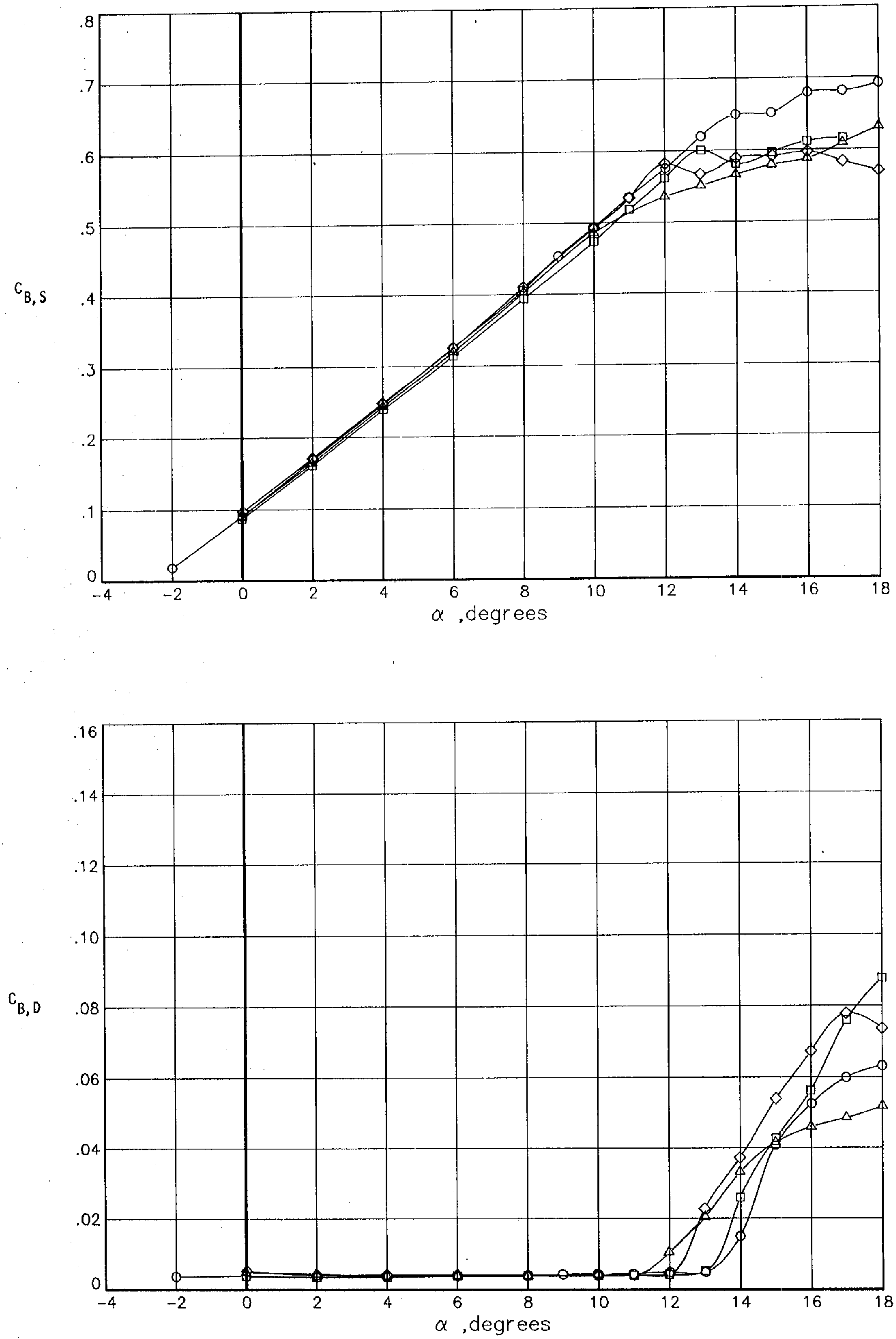


Figure 15.- Variation of steady and dynamic wing root bending moment coefficient with angle of attack for the NPL-9510 wing model. M = 0.30, P_t = 488 kPa.

	M	P_t, kPa	T_t, K	$R \times 10^{-6}$	q, kPa	V, m/sec	k, rad
○	0.30	488	300	3.12	28.9	103	1.67
□	0.30	122	110	3.12	7.2	63	2.89

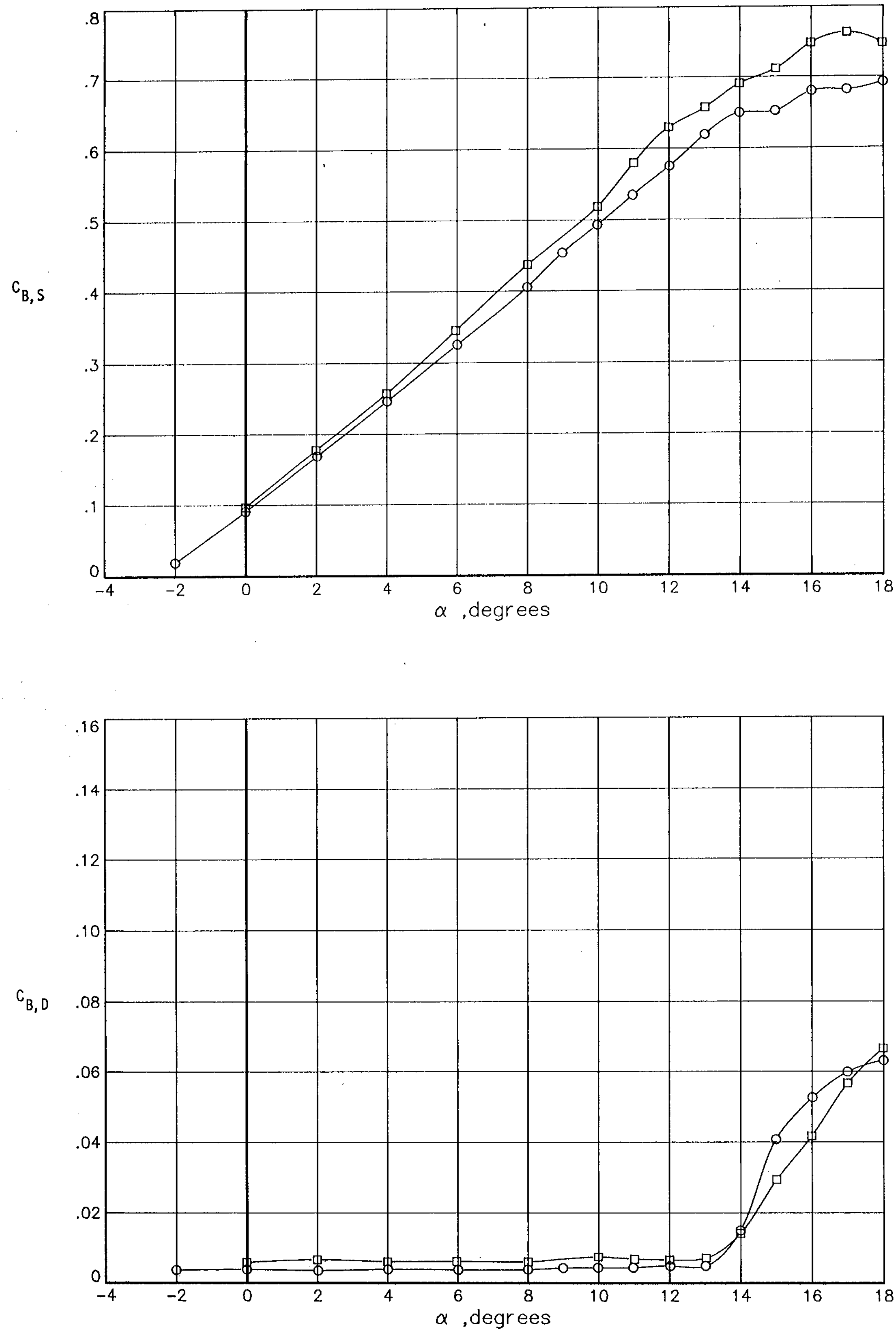
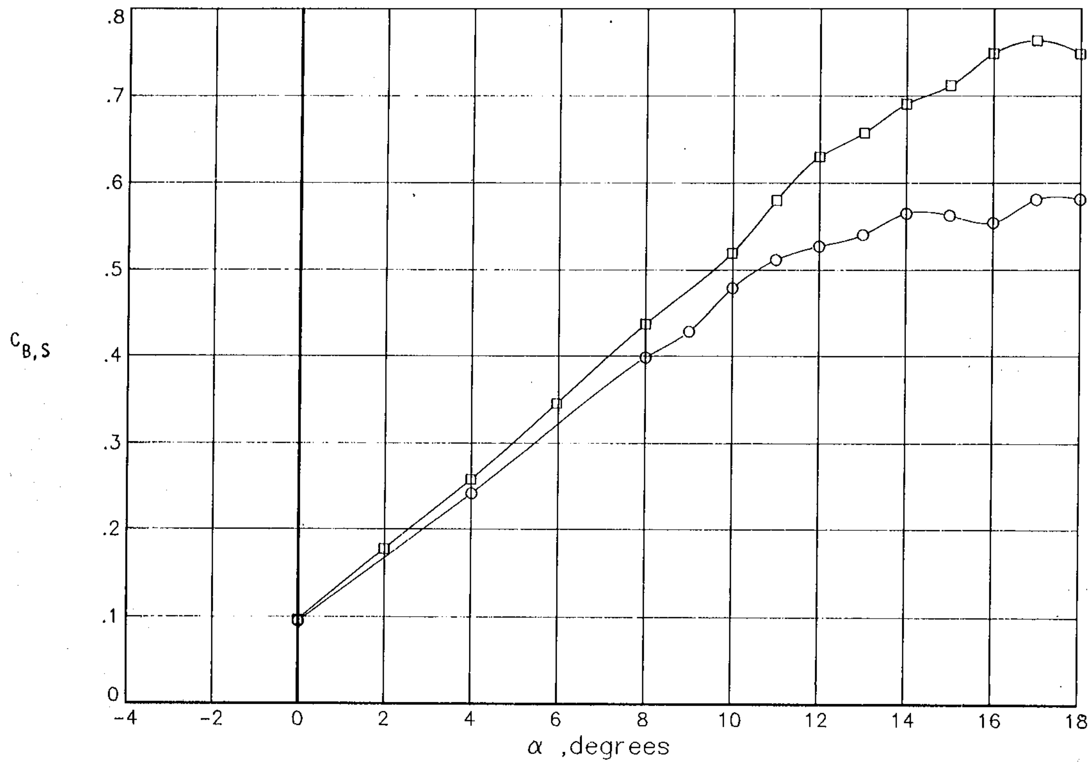


Figure 16.- Variation of steady and dynamic wing root bending moment coefficient with angle of attack for the NPL-9510 wing model. $M = 0.30$, $R = 3.12 \times 10^6$.

	M	P_t, kPa	T_t, K	$R \times 10^{-6}$	q, kPa	V, m/sec	k, rad
○	0.18	321	300	1.27	7.2	63	2.74
□	0.30	122	110	3.12	7.2	63	2.89



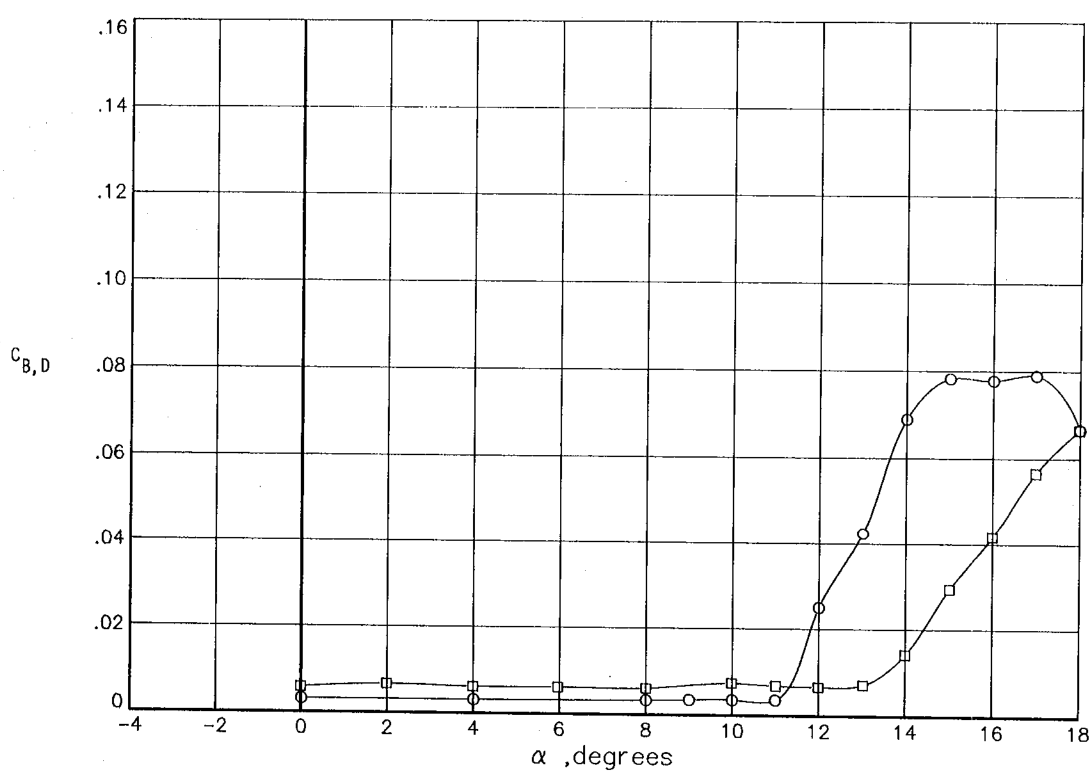


Figure 17.- Variation of steady and dynamic wing root bending moment coefficient with angle of attack for the NPL-9510 wing model. V = 63 m/sec, q = 7.2 kPa.

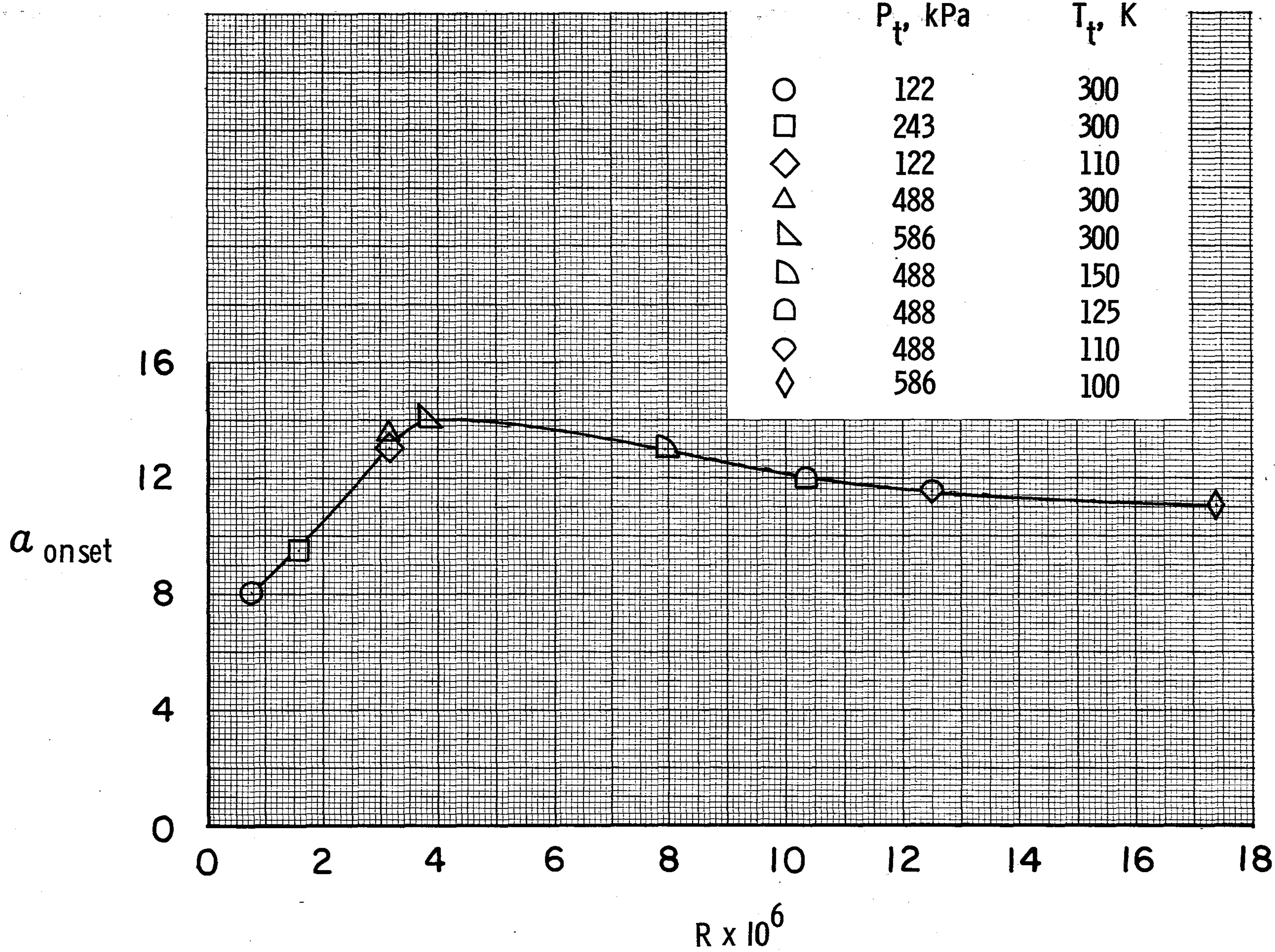


Figure 18.- Effect of Reynolds number on buffet onset angle of attack for NPL-9510 wing model. M = 0.30

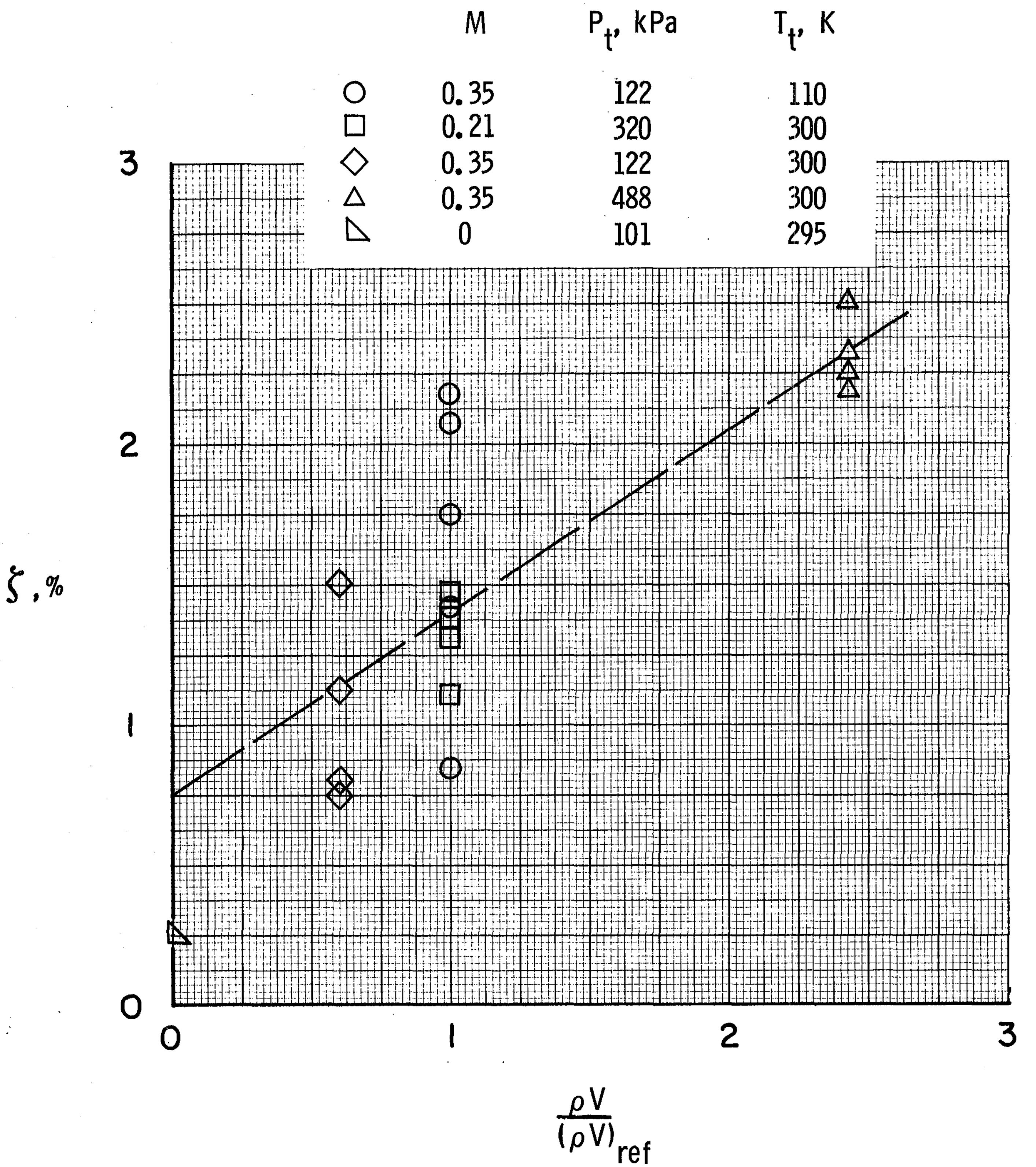


Figure 19.- Damping ratio measurements for the delta wing model.

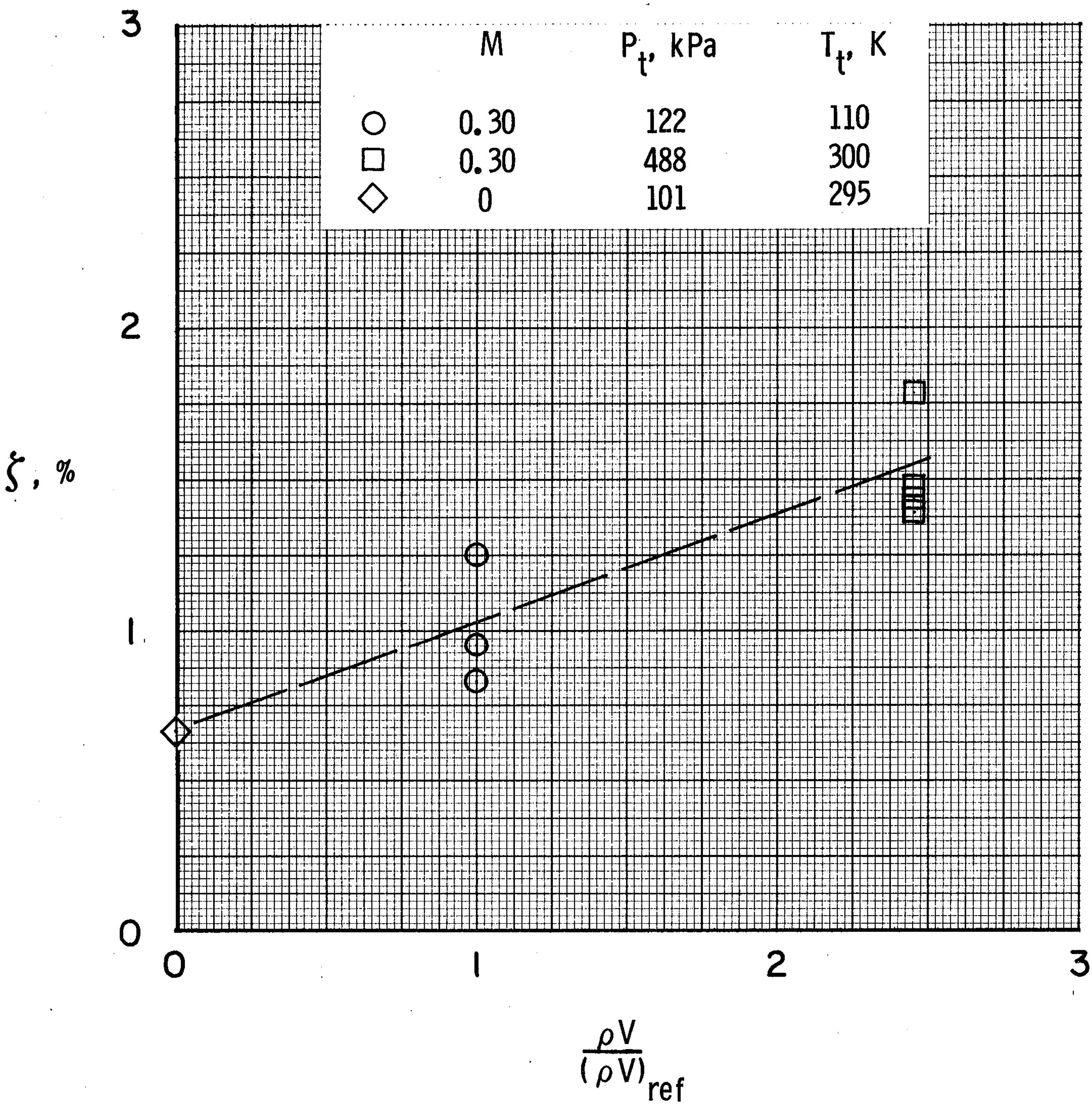


Figure 20.- Damping ratio measurements for the NPL-9510 wing model.

1. Report No. NASA TM 81923	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Preliminary Results of Buffet Tests in a Cryogenic Wind Tunnel		5. Report Date July 1981
		6. Performing Organization Code 505-31-53-01
7. Author(s) Richmond P. Boyden and William G. Johnson, Jr.		8. Performing Organization Report No.
		10. Work Unit No.
9. Performing Organization Name and Address NASA Langley Research Center Hampton, Virginia 23665		11. Contract or Grant No.
		13. Type of Report and Period Covered Technical Memorandum
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, DC 20546		14. Sponsoring Agency Code
15. Supplementary Notes		

16. Abstract

Buffet tests of two wings with different leading-edge sweep have shown that it is feasible to use the standard wing root bending moment technique in a cryogenic wind tunnel. The results for the 65° sweep delta wing indicate the importance of matching the reduced frequency parameter in model tests for planforms which are sensitive to reduced frequency parameter if quantitative buffet measurements are required. The unique ability of a pressurized cryogenic wind tunnel to separate the effects of Reynolds number and of aeroelastic distortion by variations in the tunnel stagnation temperature and pressure has been demonstrated.

17. Key Words (Suggested by Author(s)) Buffet tests Cryogenic wind tunnel		18. Distribution Statement Unclassified - Unlimited Subject Category - 02	
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 37	22. Price* A03

N-305

* For sale by the National Technical Information Service, Springfield, Virginia 22161